MSC-04241

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 71-FM-155

May 5, 1971

LUNAR SURFACE NAVIGATION ANALYSIS

Mathematical Physics Branch
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

MSC-04241

MSC INTERNAL NOTE NO. 71-FM-155

PROJECT APOLLO

LUNAR SURFACE NAVIGATION ANALYSIS

By Robert T. Savely and J. Bruce Williamson
Mathematical Physics Branch

May 5, 1971

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Approved: James C. McPherson, Chief
Mathematical Physics Branch

Approved: John P. Mayer, Chief
Mission Planning and Analysis Division

LUNAR SURFACE NAVIGATION ANALYSIS

By Robert T. Savely and J. Bruce Williamson

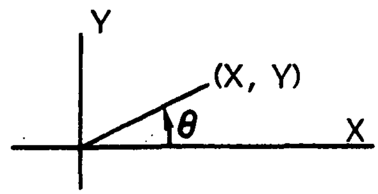
INTRODUCTION

This study was performed in order to obtain an indication of how accurately the position of the crew could be obtained by using a line-of-sight device such as a sun compass or the ROVER television camera and the prominent mountains such as Hadley and Hadley δ. The targets selected for this study will be revised when the Mapping Sciences Laboratory has completed a study of the panoramic view. The study shows that with errors of 1° (noise only) the crew position can be obtained to σ_ϕ = 850 feet and σ_λ = 400 feet using Hadley and Hadley δ. The addition of West Mountain reduced the errors to σ_ϕ = 600 feet and σ_λ = 400 feet.

ANALYSIS AND RESULTS

The standard WLS method was used where

$$\theta = \tan^{-1} \frac{Y}{X}$$



$$\Delta\theta_i = \frac{\partial\theta_i}{\partial X}\Delta X + \frac{\partial\theta_i}{\partial Y}\Delta Y$$

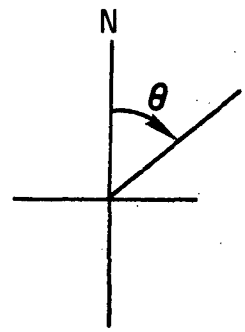
$$\frac{\partial\theta_i}{\partial X} = -Y/(X^2 + Y^2) = a_i, \quad \frac{\partial\theta_i}{\partial Y} = X/(X^2 + Y^2) = b_i$$

$$\begin{pmatrix} \sigma_X{}^2 & \sigma_{XY} \\ \sigma_{XY} & \sigma_Y{}^2 \end{pmatrix} = \alpha \begin{pmatrix} \Sigma a_i{}^2 & \Sigma a_i b_i \\ \Sigma a_i b_i & \Sigma b_i{}^2 \end{pmatrix}^{-1}$$

where $\alpha = \sigma_\theta{}^2 \quad (\text{rad})^2$

The following X and Y coordinates were estimated from the map.

Mountain	X, km	Y, km	θ, deg
Hadley	14	17	45
Hadley δ	4	-15	165
West	-26	-6	260
300°	-18	12	300
100°	25	-5	100



The following results were obtained using the preceding data and the program in the appendix.

Hadley and Hadley δ

No. of marks per target	σ_ϕ, ft	σ_λ, ft
1	1500	700
2	1050	500
3	850	400
4	750	350

Hadley, Hadley δ, and West

No. of marks per target	σ_ϕ, ft	σ_λ, ft
1	1000	700
2	700	500
3	600	400

Hadley, Hadley δ, West, and 300°

No. of marks per target	σ_ϕ, ft	σ_λ, ft
1	1000	850
2	750	650
3	450	400

All 5 targets

No. of marks per target	σ_ϕ, ft	σ_λ, ft
1	800	800
2	500	450
3	400	400

Hadley, Hadley δ, and 300°

No. of marks per target	σ_ϕ, ft	σ_λ, ft
1	1000	700
2	700	500
3	600	400

CONCLUSIONS

The requirement of near targets with the optimal separation of 90° is intuitively observed in the results as well as the value of taking three marks on each target to smooth the data and to provide a verification mark in the event that one of the three marks is inaccurate. Note that since the analysis is linear when the error models for the devices are determined the results can be scaled. It should be kept in mind that the results are noise only and that the study will be repeated with angle bias and target location error. The results of this study show that with a 1° sighting error (noise only) that the greatest accuracy that can be expected is 400 feet in latitude and longitude.

APPENDIX

LUNAR SURFACE NAVIGATION PROGRAM

APPENDIX - LUNAR SURFACE NAVIGATION PROGRAM

LANGUAGE: COMPUTER COMPLEX XTRAN

```
1CØNTINUE
P1=0.
P2=0.
P3=0.
DISPLAY          NAVIGATIØN NØISE ØNLY ERRØR ANALYSIS$
DISPLAY $INPUT FLAG: 0 FØR NØ APRIØRI, 1 FØR APRIØRI$
ACCEPT IFLAG1
IF(IFLAG),2,
WRITE (1,100)
100 FØRMAT($APRIØRI MATRIX HAS FØRM$,/,$ /   A   B   /$,/,
$ /   B   C   /$,/,$INPUT A, B, C(RETURN)$)
ACCEPT A1,A2,A3
DET=A1*A3-A2*A2
P1=A3/DET
P2=-A2/DET
P3=A1/DET
2CØNTINUE
DISPLAY $INPUT TARGET LØCATIØN AS DISPLACEMENT EAST ( X ), DISPLACMENT
 NØRTH (Y)$
READ(0,102) X,Y,IFLAG2
R=X*X+Y*Y
DTHDX=-Y/R
DTHDY=X/R
P1=P1+DTHDX*DTHDX
P2=P2+DTHDX*DTHDY
P3=P3+DTHDY*DTHDY
IF(IFLAG2),2,
DET=P1*P3-P2*P2
C1=P3/DET
C2=-P2/DET
C3=P1/DET
SIGX=SQRT(C1)
SIGY=SQRT(C3)
RHO=C2/(SIGX*SIGY)
WRITE(1,101) C1,C2,RHO,C3,SIGX,SIGY
ACCEPT IFLAG3
IF(IFLAG3),2,1
STØP
101FØRMAT(2E15.8/2E15.8/$SIGMA X =$,E15.8,$SIGMA Y =$,E15.8//
$INPUT FLAG: -1 TØ END RUN, 0 TØ PRØCEED, +1 TØ REINITIALIZE$)
102FØRMAT(2E15.8,I3)
END
```